Fabrication of Heat Storage Unit Using PCM

Alok Deshmukh[1], Utkarsh Thorat[2], Vivek Hirulkar[3], Yash Balvir[4], Darshana Bhoyar[5]

Prof. Pawan Kurwade[6]

[1,2,3,4,5]*UG Student, Department of Mechanical Engineering, Sipna College of Engineering and Technology, Maharashtra, India.*

[6]*Assistant Professor, Department of Mechanical Engineering, Sipna College of Engineering and Technology, Maharashtra, India.*

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Abstract - Thermal energy storage (TES) technologies are essential for addressing the discrepancies between energy supply and demand, ensuring that energy is available when and where it is needed. This is particularly important in applications where energy production and consumption do not align, such as in solar energy systems, where energy is only available during daylight hours, but demand may extend into the night. TES systems bridge this gap by storing thermal energy during periods of excess and releasing it when demand is high. The implementation of TES enhances the overall efficiency of heating and cooling systems by optimizing energy use and reducing waste

Key Words: phase change materials; thermal energy storage; energy efficiency; latent heat storage; heat recovery system

1.INTRODUCTION

Electricity generation can release a large amount of heat that can be stored and utilized further for cooling, heating, and other applications, which would require efficient method of TES. As in case of the Combined Heat and Power (CHP) Plants, the heat released can be extracted using heat recovery units. This process is also known as cogeneration. Heat recovery units are utilized to extract heat from the hot exhaust gases, released from combustion of fuel to run turbines or engines. This heat can then be used for heating or cooling purposes in buildings or facilities.

The heat released from the cogeneration process can be stored using various modes or methods of Thermal Energy Storage (TES). The principle of all TES applications is the same, i.e. thermal energy is supplied to storage media for periodic usage and heat extraction. TES refers to storage of energy for certain period and its subsequent usage. Applications for this technology can be found in diverse disciplines like cogeneration, Solar Power, HVAC systems, and others. With the appropriate TES system, diurnal or seasonal storage and utilization of energy is possible. This means that, in areas where heating in winter or cooling in summer is required, it is possible to store heat during the summer and utilize it in the winter, and vice-versa for cooling in summer. This method would be targeted at a large time scale across months.

2.LITERATURE REWIEW

A comprehensive review on phase change materials for heat storage applications: Development, characterization, thermal and chemical stability" by M. M. Farid, A. M. Khdair, S. A. K. Al-Hallaj, and S. M. Al Abid (2021)

• This review provides an in-depth analysis of various PCMs, including organic, inorganic, eutectic, and composite materials, focusing on their development, characterization, and thermal and chemical stability for heat storage applications.

Phase Change Materials for Energy Efficiency in Photovoltaic Systems: A Comprehensive Review" by Sarah Johnson, David Lee, and Rachel Kim (2020)

• This review focuses on the application of PCMs in photovoltaic systems to enhance energy efficiency. It examines the thermal management of PV panels using PCMs, discussing various materials and configurations to optimize performance.

Phase Change Materials in Solar Energy Applications: A Review" by John Smith, Emily Davis, and Michael Brown (2019)

• This paper reviews the integration of PCMs in solar energy systems, highlighting their role in enhancing thermal efficiencies. It covers various applications, including solar water heaters and photovoltaic systems, discussing the benefits and challenges associated with PCM implementation.

Comprehensive Review of the Application of Phase Change Materials in Residential Heating" by Laura Martinez, Robert Thompson, and Angela White (2021)

• This paper provides a detailed review of PCM applications in residential heating, focusing on their integration into building materials and systems to enhance thermal comfort and energy efficiency. It discusses various PCM types and their performance in different climatic conditions.

An overview of thermal energy storage systems" by Guruprasad Alva, Yaxue Lin, and Guiyin Fang (2018)

• This comprehensive review categorizes TES systems into sensible, latent, and chemical storage, analyse their materials, design parameters, and operational issues. It discusses applications across various temperature ranges and sectors, including buildings, textiles, and automobiles.

Thermal energy storage in district heating and cooling systems: A review" by Andrea Arteconi, Nicola J. Hewitt, and Francesco Polonia (2019)

• This paper explores the integration of TES in district heating and cooling systems, evaluating both short-term and long-term storage solutions. It assesses the performance, advantages, and limitations of various TES technologies within this network.

Thermal Energy Storage for Grid Applications: Current Status and Emerging Trends" by Diana Enescu, Gianfranco Chicco, Radu Porumb, and George Seritan (2020)

• This article reviews the role of TES in grid applications, focusing on its potential to balance supply and demand, integrate renewable energy sources, and enhance grid stability. It discusses current technologies and emerging trends in the field.

Review on the sustainability of phase-change materials used in buildings" by R. Aridi, A. Yehya (2022)

• This review examines the sustainability of PCMs in buildings, considering performance, economic, environmental, and social aspects. It highlights the role of PCMs in reducing energy consumption and greenhouse gas emissions.

Environmental and economic management study of phase change material integrated bifacial photovoltaic thermal greenhouse drying system" by S. M. Al-Abidi, M. M. Farid, S. A. K. Al-Hallaj (2022)

• This study explores the integration of PCMs in photovoltaic thermal systems for greenhouse drying, assessing environmental and economic impacts. It demonstrates how PCMs can enhance system efficiency and reduce operational cost.

Energy, environmental, and economic analysis of different buildings with phase change materials" by J. Zhang, Y. Zhang, Z. Zhang (2020)

• This paper analyses the impact of PCMs on energy efficiency, environmental performance, and economic feasibility in various building types. It quantifies energy savings and emission reductions associated with PCM integration.

3.PHASE CHANGE MATERIAL (PCMs) FOR THERMAL ENERGY STORAGE

Phase Change Materials (PCMs) are at the core of Latent Heat Storage (LHS) technology. These materials store and release large amounts of heat energy during phase transitions, making them highly efficient for TES applications.

1.3.1 Types of Phase Change Materials PCMs are classified into three major categories:

• Organic PCMs: Includes paraffin waxes and fatty acids, known for their chemical stability and non-corrosive nature.

• Inorganic PCMs: Includes salt hydrates and metals, offering high thermal conductivity but prone to phase separation.

• Eutectic PCMs: A combination of organic and inorganic components to enhance thermal properties.

1.3.2 Selection Criteria for PCMs the choice of PCM depends on several key properties:

• Melting and Freezing Temperature: Should align with the application's temperature requirements.
• High Latent Heat of Fusion: Ensures maximum energy storage capacity.
• Thermal Stability and Non-Toxicity: Essential for long-term and safe operation.

1.3.3 Challenges in PCM-Based TES While PCMs offer significant advantages, they also present challenges such as:
• Low Thermal Conductivity: Limits heat transfer efficiency, requiring enhancement techniques.
• Supercooling Effect: Causes irregular melting and solidification behavior.
• Material Compatibility and Durability: Long-term performance and containment need improvement.

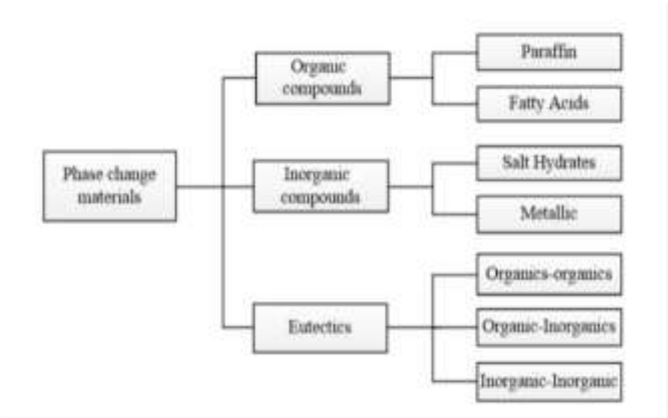

Fig. Classification of Phase Change Material

Phase Change Materials (PCMs) are substances that absorb and release thermal energy during the process of melting and solidifying at a specific temperature. They are highly effective in thermal energy storage systems because they can store large amounts of energy in the form of latent heat. When a PCM melts, it absorbs heat from the surroundings without a significant change in temperature, and when it solidifies, it releases that heat back into the environment. One of the most commonly used PCMs in thermal energy storage applications is **paraffin wax**, which belongs to the class of organic PCMs.

Paraffin wax has several advantageous properties such as high latent heat of fusion, chemical stability, non-corrosiveness, non-toxicity, and a relatively narrow melting temperature range. It typically melts between 45°C to 65°C depending on its composition, making it ideal for medium-temperature thermal storage applications like solar heating, electronics cooling, and building temperature regulation. In addition, paraffin wax does not undergo significant supercooling or phase separation, which enhances its reliability and performance over multiple thermal cycles. In the context of your project, using paraffin wax as the PCM allows for efficient thermal energy storage and retrieval, contributing to better energy management and system efficiency. Its availability and low cost further make it a practical choice for experimental and real-world applications.

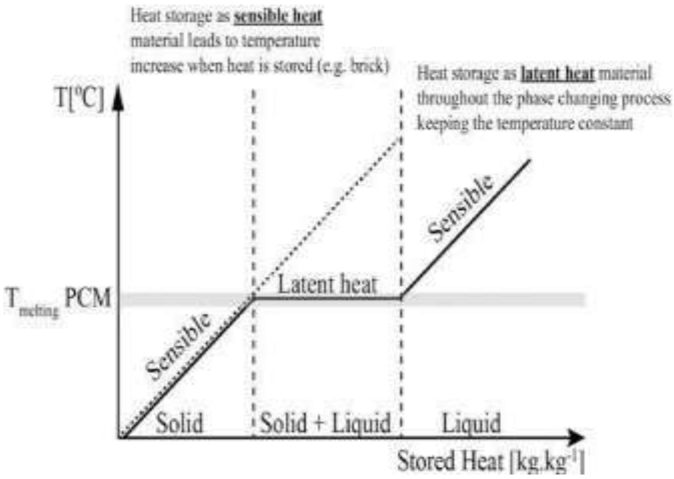

Fig. Heat transfer regions of PCM

4.SIGNIFICANCE OF THERMAL ENERGY STORAGE SYSTEM

Thermal energy storage (TES) technologies are essential for managing the discrepancies between energy supply and demand, thereby improving the efficiency of heating and cooling systems. These technologies store thermal energy to be used later, which helps in optimizing energy use and reducing waste. TES is particularly crucial for effective waste heat utilization and solar energy conservation, making it a key component in sustainable energy solutions.

TES systems address the timing mismatch between energy availability and energy needs. By storing energy during periods of low demand or high availability (such as daytime for solar energy) and releasing it during peak demand or low availability (such as nighttime), TES systems enhance the overall efficiency of energy systems. This capability is vital for improving the performance of various applications, including space and water heating, waste heat recovery, cooling, and air conditioning. The ability of TES to balance energy supply and demand makes it an indispensable technology in modern energy management.

1.1.1 Concept of Thermal Energy Storage

TES involves the temporary storage of thermal energy in a medium to be retrieved and used at later time. The stored energy can be derived from different sources, such as solar energy, industrial waste heat, or geothermal systems. TES systems help balance energy demand and supply, ensuring a stable and efficient energy network.

1.1.2 Types of Thermal Energy Storage

TES systems can be broadly classified into three categories:

- **Sensible Heat Storage (SHS):** Involves storing energy by raising the temperature of a material, such as water or rocks, without a phase change.
- **Latent Heat Storage (LHS):** Utilizes Phase Change Materials (PCMs) that absorb and release energy during phase transition.
- **Thermochemical Storage (TCS):** Involves reversible chemical reactions to store and release energy efficiently.

1.1.3 Role of TES in Energy Systems

TES plays a significant role in various applications, including:

- **Renewable Energy Storage:** Storing excess solar or wind energy for later use.
- **HVAC and Building Applications:** Enhancing heating and cooling efficiency in buildings.
- **Industrial Waste Heat Recovery:** Capturing and reusing heat generated in industrial processes.

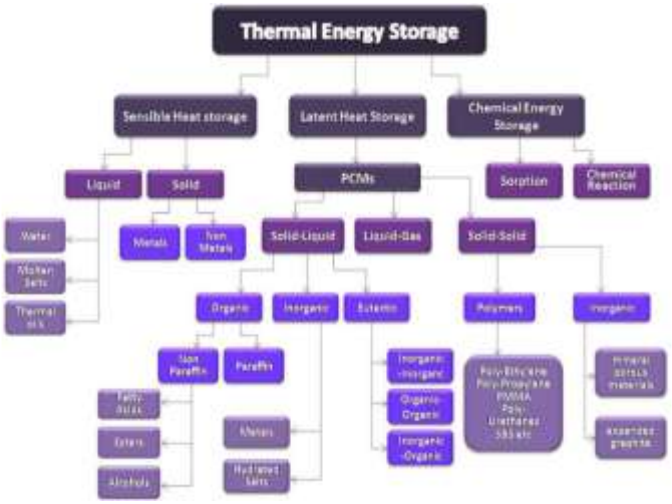

Fig. Classification of thermal energy storage types and materials.

5.WORKING

The main goal of the project is to use heat energy for cooking after daylight without the use of solar cell. The working of this unit is simple and procedure can be carried out easily. In the above diagram we can see that there are two major circuits to be run in this project. Circuit-1 consists of an oil tank, another tank having Phase change material stored in it, Oil pump, three phase motor, diaphragm control valve-1, diaphragm control valve-2 and the copper tube connecting the above equipment and heating coil acts acting as sun. Circuit-2 consist of PCM tank, Oil pump, three phase motor, two containers, diaphragm control valve-3, diaphragm control valve-4 and copper tubes connecting the second circuit.

The circuit 1 starts from the oil tank. The heating coil acts as sun for providing heat energy to the system. The heating coil is used to increase the temperature of the oil present in the oil tank. The oil present in the oil tank after reaching the required temperature, is further passed on in the circuit with the help of fuel pump. The copper tube from which oil is leaving the oil tank is kept at a certain height closer to the heater in such a manner that hot fluid can be carried out in the system. The copper tube entering the oil tank is kept deep in the oil tank so that the cold oil entering the tank can be collected at the bottom of the tank.

The oil pulled from the tank is further flown into the PCM storage tank with the help of copper tube. The PCM (In this project PCM used is paraffin wax having melting temperature of 37°C and melting temperature of 370°C) available in the storage tank is the most important component as it will absorb the heat present in the copper tube. The PCM storage tank consists of copper tube in a spiral way so that the PCM available in the tank will absorb heat quickly. The spiral of copper tube can be increased and decrease according to required amount heat to be given. When PCM reaches the required temperature, both the diaphragm control valve, Valve1 and Valve2 in the circuit-1 is totally closed. The motto of circuit-1 is completed.

The circuit-2 should be started immediately after closing valve-1 and valve-2 and opening valve-3 and valve-4. When valve-1 and valve-2 are closed, valve-3 and valve-4 are opened so that the flow of oil is continue. Now, the oil running in circuit-2 has some amount of heat running in the circuit. When the oil is transferred in the container kept on the top of the apparatus, this running of oil in circuit-2 reduces the heating temperature present in the oil. To maintain this temperature, the oil is continuously flown through the Phase Change Material (PCM) with the help of copper tube.

The container kept on the top of apparatus has another small container in which water is kept. Both the containers are attached with the help of nut and bolt. Both the containers have some space between them so that there should be continuous flow of oil in the circuit-2. This continuous flow of oil will increase the temperature of the water present in the small container. This continuous flow of oil in circuit-2 will increase the temperature of the small container having water in it Thereby, completing our goal to use heat energy for cooking after daylight without the use of solar cell.

6.APPLICATION

Applications in Cooking Systems Solar Cookers: PCMs are used in solar cookers to store solar energy during peak sunlight hours and release it for cooking when sunlight is limited. This application allows for continuous cooking even during cloudy periods or at night. Induction Cooktops: PCM technology can be integrated into induction cooktops to stabilize temperatures and improve energy efficiency. The stored heat helps maintain a consistent cooking temperature. Thermal Ovens: Ovens with PCM storage can provide a more uniform temperature, reducing hot spots and ensuring even cooking. PCM-enhanced ovens can also retain heat Solar Thermal Energy Storage: PCMs are used in conjunction with solar thermal systems to store excess heat generated during the day for use during the night or periods of low solar radiation, improving the efficiency and reliability of solar energy systems.

7.FUTURE SCOPE

Efficiency Improvement: Future research aims to enhance the efficiency of PCM-based heat energy storage systems by optimizing PCM selection, encapsulation techniques, and system design. Improvements in thermal conductivity, latent heat storage capacity, and cycling stability are crucial for increasing overall system performance.

Material Innovation: Ongoing research focuses on the development of novel PCM materials with tailored properties, such as high thermal conductivity, tunable phase change temperatures, and improved stability. Nanocomposites, hybrid materials, and bio based PCMs are areas of active investigation.

Application Diversification: PCM-based heat energy storage finds applications in various sectors, including buildings, solar thermal systems, HVAC (heating, ventilation, and air conditioning), and waste heat recovery. Future scope involves exploring new application areas and integrating PCM technology into emerging energy storage solutions, such as grid-scale storage and electric vehicle thermal management.

Advanced Manufacturing Techniques: Advances in fabrication techniques, such as additive manufacturing (3D printing), microencapsulation, and scalable production methods, enable cost-effective and customizable fabrication of PCM-based heat storage units. Future research focuses on scaling up production and reducing manufacturing costs to facilitate widespread adoption.

Integration with Renewable Energy Systems: PCM-based heat energy storage complements renewable energy sources, such as solar and wind power, by providing dispatchable and grid-balancing capabilities. Future scope includes integrating PCM storage units into renewable energy systems to enhance energy reliability, grid stability, and energy independence.

In summary, the fabrication of heat energy storage units using PCMs offers promising opportunities for improving energy efficiency, reducing greenhouse gas emissions, and advancing sustainable energy solutions.

8.CONCLUSION

In conclusion, the fabrication and testing of the Heat Energy Storage Unit (HESU) employing Phase Change Materials (PCMs) have demonstrated significant potential for enhancing energy efficiency and sustainability in various thermal energy storage applications.

Through this project, we have successfully designed and constructed a compact and reliable HESU capable of storing and releasing thermal energy efficiently. By harnessing the latent heat capacity of PCMs, our system effectively stores energy during the melting phase and releases it upon solidification, thereby enabling thermal energy management with minimal temperature fluctuations.

Our experimental results have confirmed the viability and effectiveness of the HESU in providing stable and controlled thermal energy storage. The system exhibits rapid charging and discharging capabilities, allowing for quick response to varying energy demands and fluctuations in renewable energy sources.

Furthermore, the use of PCMs offers several advantages, including high energy storage density, thermal stability, and long-term durability, making it a promising solution for addressing energy storage challenges in diverse applications such as solar thermal systems, building HVAC systems, and industrial processes.

However, despite the promising results, some challenges and areas for further improvement have been identified. These include optimizing the selection and encapsulation of PCMs to enhance thermal conductivity and cycling stability, as well as scaling up the system for commercial applications while maintaining cost-effectiveness.

In conclusion, the development of HESUs utilizing PCMs represents a significant step towards achieving sustainable and efficient energy utilization. Continued research and innovation in this field will be crucial for unlocking the full potential of thermal energy storage technologies and advancing towards a greener and more sustainable future.

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